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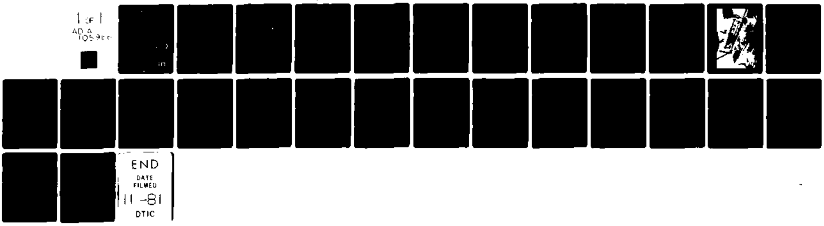

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BIAS BUOY ARMORED TOW CABLE

FINAL TECHNICAL REPORT

CLIN 0001

Contract N00173-80-C-0361

ITT Project 36047011

For Period

22 September 1980 to 1 July 1981

Prepared for:

Naval Research Laboratory
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This report covers the total contract period from September 1980 to July 1981 of the development of a fiber optic armored bias buoy tow cable. The final cable design consists of six graded-index optical fibers and six electrical wire conductors. There are two layers of contrahelically applied plow steel armor. This armored hybrid undersea tow cable design will be used as a prototype of a link which connects an outboard bias buoy sensor deployed from a fleet submarine to an inboard data processing center.

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1.0 INTRODUCTION

The bias buoy armored tow cable, contract N00173-80-C-0361, is a follow-on to the fiber optic cable design study successfully completed under Naval Research Laboratory (NRL) contract N00173-79-C-0466. This design study has shown that optical fibers can withstand the stresses associated with armored tow cables. Three new designs optimized under contract N00173-79-C-0466 have outside diameters (od) of 0.94 cm, 1.12 cm, and 1.27 cm, respectively. This report describes the construction and development of the 1.27 cm od cable.

The 1.27 cm od cable design was selected for further development by NRL because this design has the highest utility for current and future planned applications requiring increased cable strength. The 1.27 cm od design contains six graded-index optical fibers and six number 20 AWG stranded copper conductors. Two layers of galvanized improved plow steel (GIPS) applied in a torque balanced configuration were used to armor the cable. The cable is designed to deploy, retrieve, and support a buoy which is towed just under the surface from a submarine. The cable carries signals between the submarine and the buoy. Electrical power is supplied to the buoy from the submarine via the cable.

2.0 CABLE DESIGN

As stated in the introduction, NRL selected the largest design resulting from contract N00173-79-C-0466 which optimized three fiber optic armored tow cables. Each of these three optimized designs consisted of optical fibers and wire conductors.

The diameters of the three optimized cables are 0.94 cm, 1.12 cm, and 1.27 cm, respectively. Breaking strength of each of the cables increased with the diameters, starting with 10,000 lb for the 0.94 cm od and progressing to 15,000 lb at 1.12 od and 20,000 lb for the 1.27 cm od.

The optimized armor package with the 1.27 cm diameter (0.500 in) and the (20,000 lb) 89 kN breaking strength provides the extra strength needed for anticipated future buoy payloads. Because of this, NRL decided upon further development of the cable design with the 1.27 cm od.

The design goals for the cable optical parameters after cabling and after armoring were

a. Attenuation: <8 dB/km at 850 nm wavelength

b. Dispersion: <2 ns/km at 900 nm wavelength

Figure 2.0-1 shows the 1.27 cm od optimized cable design selected by NRL for development. The following paragraphs describe the component elements of the cable design shown in Figure 2.0-1.

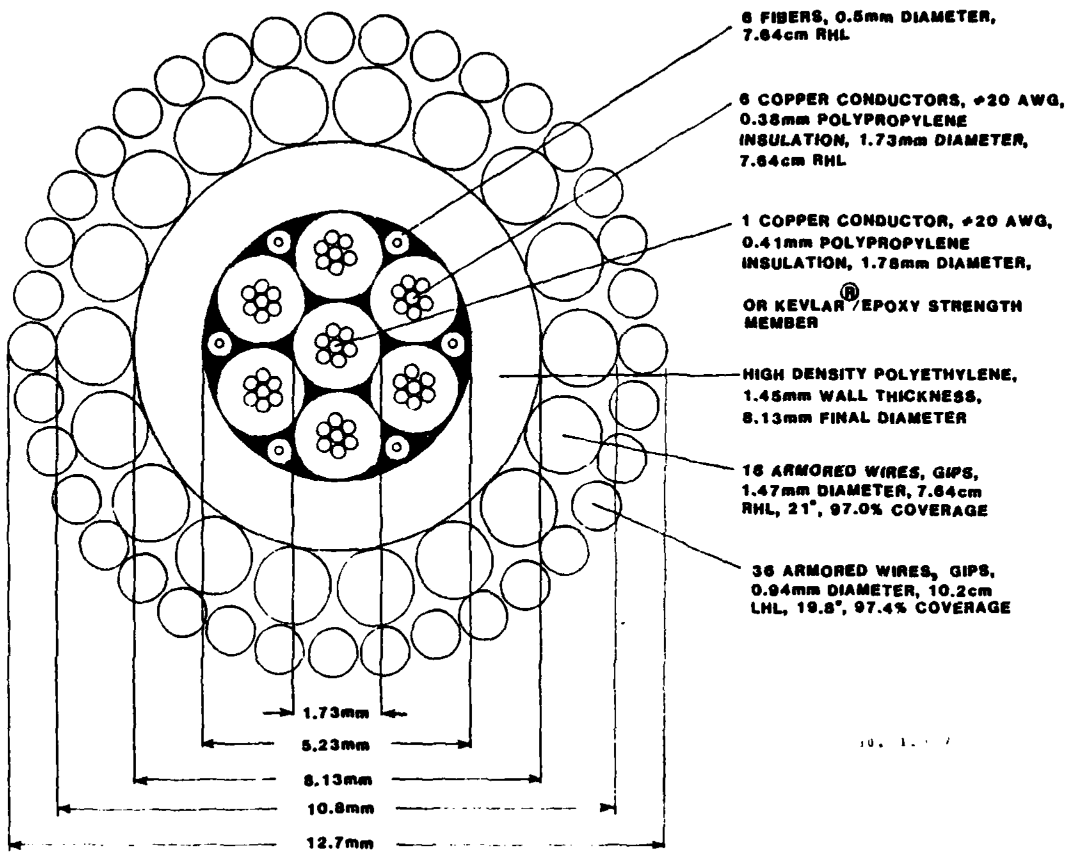

Figure 2.0-1. Bias Buoy Tow Cable.

2.1 Optical Fibers

The light transmitting elements of the optical cable are optical fibers. Each optical fiber consists of a glass optical core and a glass cladding. Mechanical strength of the optical fibers is preserved by the addition of a thermosetting low modulus elastomer coating. The coating material is silicone room temperature vulcanizing (RTV). The silicone RTV coating provides environmental protection for the pristine fiber because it is applied on-line in the draw process immediately after the fiber is drawn from the draw tower furnace. Later, in the drawing process, an additional hard buffer coating of a high modulus thermoplastic elastomer is applied over the silicone RTV. The trade name for the plastic outer buffer material is Hytrel®. Consequently, the optical fibers are protected by a dual plastic system consisting of an elastomer inner buffer and a hard polymer outer buffer. This optical fiber construction permits the fibers to be helically wound and tightly bound in the cabling process without incurring excessive microbending losses. In addition, the optical fibers are exceedingly strong. The fibers used in this cable design were 100% proof-tested at 1378 MPa (200 kpsi).

The specifications for the graded-index optical fibers employed in the cable construction shown in Figure 2.0-1 are as follows:

a. Fiber core 50 ±5 μm

b.	Fiber od	125 ± 5 μm
c.	Attenuation	<5 dB/km at 850 nm
d.	Numerical aperture	0.22 ±0.03
e.	Dispersion	<2 ns/km at 900 nm
f.	Proof-test level	1378 MPa

A Dow Corning Sylgard® 184 silicone RTV protective buffer is applied by dipcoating to a finished diameter of 300 μm during fiber drawing. This protective coating guards the fibers from any initial handling or from foreign substances that may damage or reduce the fiber's strength. The properties of the Dow Corning Sylgard® 184 material are

a.	Specific gravity	1.05
b.	Durometer, Shore A	35
c.	Brittle point	<-100°C
d.	Ultimate tensile	>6.2 MPa

The silicone RTV coated fibers are then overjacketed with a Hytrel® layer by extrusion for additional protection to a finished diameter of 500 μm. The Hytrel® has the following properties:

a.	Specific gravity	1.25
b.	Durometer, Shore D	72
c.	Brittle point	<-70°C
d.	Ultimate tensile strength, MPa	>34

2.2 Void-Filling Compound

The void-filling compound used was a blend by weight of the amorphous polypropylene and polyisobutylene. All cables were filled in-line with the cabling operation and also during extrusion of the jacket. Figure 2.2-1 shows the void-filling application.

2.3 Primary Copper Wire Insulation - Polypropylene

The compound extruded over the individual copper conductors was polypropylene. The polypropylene insulating material has the following properties:

a.	Specific gravity	0.903
b.	Durometer, Rockwell	R65
c.	Brittle point	<-15°C
d.	Ultimate tensile strength, MPa	23.4

2.4 Center Element

Two options were tried. In option 1, one number 20 AWG copper conductor with 0.38 mm polypropylene insulation having a total od of 1.73 mm was used as a central strength member. In option 2, a Kevlar®/epoxy central strength member was used. The load bearing central strength member was a design consisting of 10 Kevlar® fibers and 3 S-glass fibers embedded in an Airlog 380-6 epoxy. The od is 1.78 mm. Two options were selected because it was felt

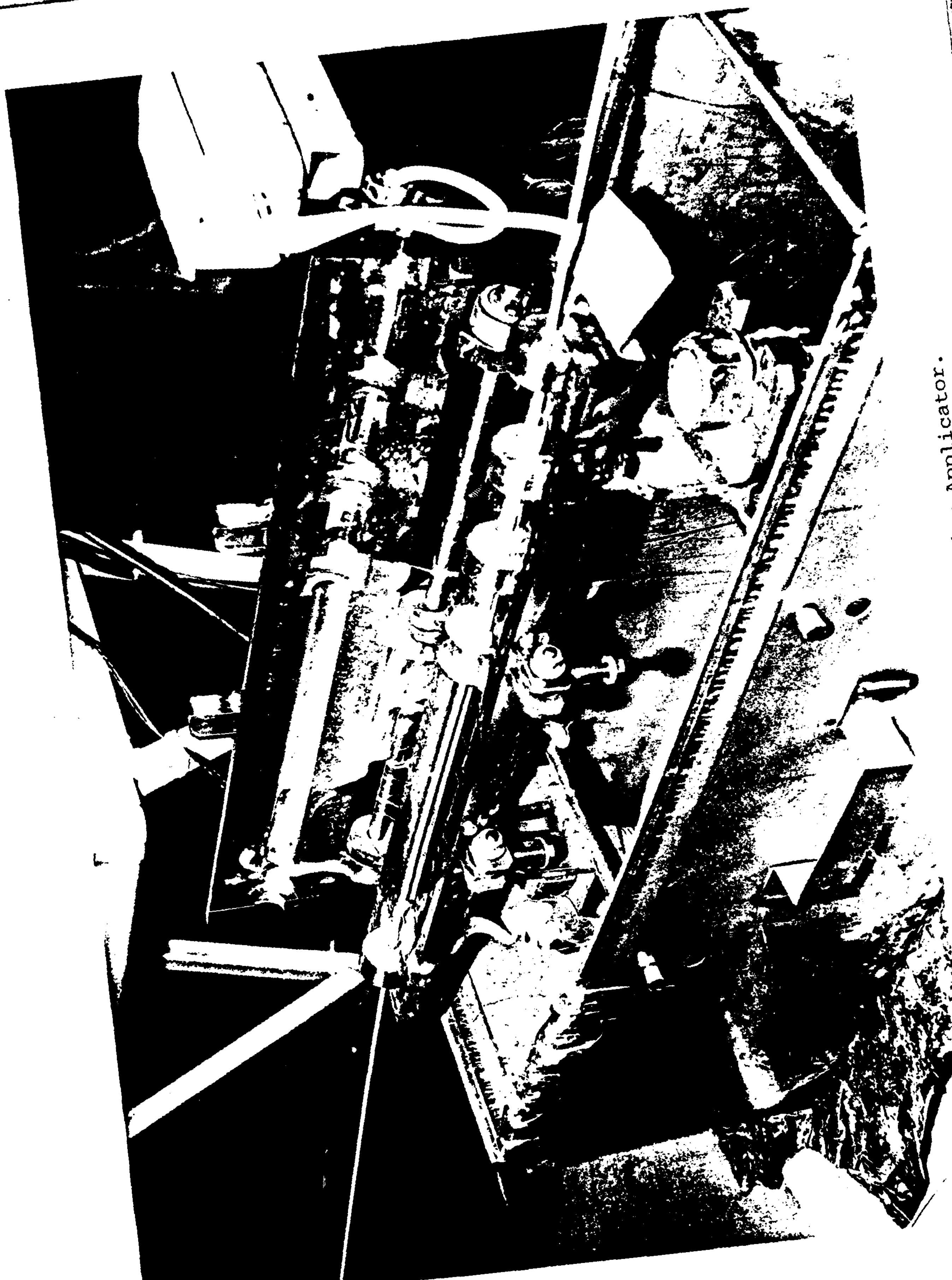

Figure 2.2-1. Void-Filling Applicator.

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S-glass would provide more strength to the core but there was some concern about its ability to survive flexure testing.

2.4.1 Option 1

This option consists of a central strength member containing the same gage stranded wire as the surrounding copper wire conductor elements of the hybrid fiber optic cable, i.e., 1.73 mm in polypropylene insulated od. The oxygen free, high conductivity (OFHC) stranded dead soft copper wire has 7/28 (seven strands of number 28 AWG) concentric stranded high purity copper. Properties of the polypropylene were described in paragraph 2.3.

2.4.2 Option 2

The composite central strength member of 10 Kevlar® yarns, 3 S-glass yarns, epoxy filled, with a Hytrel® 4056 jacket was purchased from Air Logistics Corporation. The central strength member was 1.78 mm od and met the following requirements:

a.	Epoxy matrix	Airlog no 380-6
b.	Jacket	Hytrel® 4056
c.	Tensile strength, MPa	1963
d.	Breaking load, N	1021
e.	Load at % strain, N	409
f.	Tensile modulus, MPa	78,546

g. Breaking strength >3.59 kN

h. Weight 3.44 kg/km

This strength member was considered for the center element to provide more ruggedness and to minimize elongation of the core prior to the armoring process.

2.5 Polyethylene Core Jacket

The core was jacketed with a high density polyethylene jacket material that meets the following requirements:

a.	Density	0.95 g/cm^3
b.	Brittle point	<-76°C
c.	Minimum elongation	400%
d.	Jacket wall thickness	1.45 mm

2.6 Color-Coding Method

In each cable, all wire conductors were color coded by standard color pigment additives in the polypropylene. Each wire conductor was colored blue, orange, green, white, brown, red, and yellow. This allowed the intervening white colored optical fibers to be identified in the manner described in Table 2.6-1 so as to provide polarity and end identification.

It is readily seen that each white optical fiber is identified by the adjacent (bracketed) color-coded wire conductors, i.e.,

red/green, green/blue, blue/white, white/yellow, yellow/orange, and orange/red.

2.7 Electrical Conductors

There are six electrical conductors in the design (option 2) with the Kevlar®/epoxy central strength member. The option 1 design has an additional copper conductor in the center in place of the Kevlar®/epoxy central strength member. The electrical conductors are comprised of soft drawn oxygen free copper for high flex-life and best conductivity.

The concentric stranded bare copper wire conductors consist of 7/28 concentric lay type stranding. All seven strands are number 28 AWG. One wire serves as a central core. The other six helically laid wires have the same direction of lay. Hence, the term unidirectional concentric stranded wires applies in this case.

The 7/28 construction of stranded annealed uncoated copper wire has an equivalent AWG number 20 size. The annealed copper properties for this bare wire are

a.	Tensile strength	34,000 lb/in^2
b.	Resistivity (maximum)	10.5 ohms per 1000 ft at +20°C
c.	Weight	3.47 lb/M ft or 5.16 kg/km

Table 2.6-1. Color-Coding Method.

Fiber Color Coding	Wire Conductor Color Coding
1. White	1. Center conductor, brown
2. White	2. Red
3. White	3. Green
4. White	4. Blue
5. White	5. White
6. White	6. Yellow
	7. Orange

d.	Diameter	0.038 in od or 0.965 mm od
e.	Nominal dc resistance at 20°C	9.6 ohms/M ft or 31.5 ohms/km

Each of the bare copper conductors was insulated with a primary jacket of polypropylene as described in paragraph 2.3. The total diameter of each electrical conductor was 1.73 mm after extrusion of the primary polypropylene jacket.

The individually stranded solid uncoated annealed copper wire elements which are number 28 AWG have the following properties:

a.	Diameter	0.0126 in or 12.6 mil or 0.320 mm
b.	Cross section	159 circular mil or 0.0804 sq mm
c.	Nominal dc resistance at +20°C	67.4 ohms/M ft or 221 ohms/km
d.	Weight	0.481 lb/M ft or 0.716 kg/km or 2080 ft/lb or 1400 m/kg

2.8 Armoring

The strength members in this cable design consist of two layers of contrahelically applied GIPS which are coated with a corrosive inhibiting additive. These strength members form the outermost surface of the cable.

The armor package consists of an inner layer with 18 wires (each 1.50 mm diameter) of GIPS, 7.64 cm, right-hand lay, and an outer layer with 37 wires (each 0.90 mm diameter), GIPS, 8.89 cm, left-hand lay.

3.0 FABRICATION TECHNIQUE

The two optional designs were made in exactly the manner described in the following paragraphs except for the two options for central strength members defined in paragraph 2.4 and exactly as shown in Figure 2.0-1.

The manufacturing specifications were as follows:

a. A composite central strength member with a Hytrel® 4056 jacket at 1.78 mm od was used for the core (option 2). In option 1, an extra wire described in e below was used.

b. Six buffered graded-index optical fibers were helically applied with a 7.64 cm right-hand lay.

c. The AFAX-600 void-filling compound was pumped under pressure into the cable interstices just prior to jacketing in-line with the extruder and during the cabling operations.

d. The AWG 20 wire cable singletons were pressure extruded with a primary insulation 0.38 mm polypropylene (Hercules Profax SE-191) to a 1.73 mm finished diameter.

e. The number 20 AWG stranded copper conductors are constructed of seven concentric strands of number 28 AWG, soft drawn OFHC copper. The insulated conductors were helically applied with a 7.64 mm right-hand lay.

f. The core cable jacket is a high density polyethylene jacket material, pressure extruded to a wall thickness of 1.45 mm, or an od of 8.13 mm.

g. Armoring accomplished as defined in paragraph 2.8 was performed by an outside vendor, Vector Cable Company, in Sugarland, Texas. The armoring operation compresses the core to a 7.87 mm effective final diameter. This is caused by embedment of the armor wires into the polyethylene core jacket and volume compression of the core. The components were (1) inner armor layer: 18 armored wires GIPS, 1.47 mm diameter, 7.64 cm right-hand lay, 21°, 97.0% coverage, and (2) outer

armor layer: 36 armored wires GIPS, 0.94 mm diameter, 10.2 cm left-hand lay, 19.8°, 97.4% coverage.

3.1 Manufacturing Problems

The two cable design configurations were fabricated at ITT EOPD without any manufacturing difficulty. The armoring vendor, Vector Cable, reportd that armoring was performed without any manufacturing difficulty. The center element with the Kevlar®/epoxy strength member was eliminated as an option because of failure during flex-testing.

4.0 TESTING AND INSPECTION RESULTS

The bias buoy armored tow cable core and finished cable were subjected to the tests listed below. Data is recorded in the succeeding paragraphs.

a. Cable diameter inspection

b. Jacket quality inspection

c. Optical attenuation was measured at 0.85 μm before and after cabling and after armoring. This data is recorded in Table 4.0-1. Optical attenuation measurement over the spectrum from 0.82 μm to 1.09 μm at four wavelengths (0.82, 0.85, 1.06, 1.09) after armoring is described in Table 4.0-2.

d. Pulse dispersion measured at 0.9 μm, before and after cabling, and after armoring is shown in Table 4.0-1.

e. Fiber NA, core size, and cladding diameter measurements data is recorded in Table 4.0-1.

f. Direct current resistance of all electrical conductors is shown in Table 4.0-3, item a.

g. High potential measurement between electrical conductors and to armor wires is discussed in Table 4.0-3, item b.

h. Insulation resistance of electrical conductors is shown in Table 4.0-3, item c.

The test results were furnished with shipment of the cable. Data for the cable tested is shown in the following paragraphs, and in Tables 4.0-1 and 4.0-2.

4.1 Cable Diameter

The overall cable diameter measured 1.27 cm ±0.13 mm.

Table 4.0-1. NRL Bias Buoy Armored Tow Cable.

	Fiber			Cabled (832 m)		Armored (561 m)			
	CVD No	Atten	Disp	Atten	Disp	Atten	Disp	NA	Core (μm)
Red-Green	90098	3.96	1.91	4.50	1.73	5.18	1.79	0.24	49 x 48
Green-Blue	30959	4.47	0.98	5.83	0.83	7.36	0.95	0.24	51 x 50
Blue-White	30959	4.47	0.98	6.41	1.28	6.43	1.26	0.24	51 x 50
White-Yellow	90098	3.96	1.91	4.61	3.63	5.99	1.42	0.24	49 x 48
Yellow-Orange	21366	3.46	0.44	3.78	0.56	5.04	0.64	0.23	51 x 50
Orange-Red	30959	4.47	0.98	5.44	1.19	6.47	1.56	0.24	51 x 50

NOTES: Attenuation in dB/km at 850 nm wavelength.
Dispersion in ns/km at 900 nm wavelength.

Table 4.0-2. Attenuation of Armored Cable at Four Wavelengths

	0.82 μm	0.85 μm	1.06 μm	1.1 μm
Red-Green	6.38	5.18	3.65	3.25
Green-Blue	8.09	7.36	6.02	5.38
Blue-White	7.94	6.43	4.87	5.08
Yellow-White	6.74	5.99	3.84	3.27
Orange-Yellow	5.66	5.04	3.91	3.64
Red-Orange	6.94	6.47	4.32	4.12

NOTE: Attenuation readings are in units of dB/km at each indicated wavelength.

Table 4.0-3. Bias Buoy Armored Tow Cable Electrical Test Results.

a. dc resistance of electrical conductors:

Conductor color:	blue	= 17.26 ohms
	orange	= 17.18 ohms
	green	= 17.22 ohms
Center conductor:	brown	= 17.26 ohms
	white	= 17.18 ohms
	red	= 17.19 ohms
	yellow	= 17.17 ohms

b. Hi pot on electrical conductor: Accepted

All conductors together against armor wire -

2000 Vdc for 5 min in air

c. Insulation resistance of the electrical conductors to each other is $>1 \times 10^{11}$ ohms after 5 min; tested with 500 Vdc

4.2 Weight

The overall cable weight was 548 kg/km (368 lb/kft).

4.3 Length

The minimum finished cable length to be provided was 550 m (1800 ft). The cable shipped to NRL was 561 m.

4.4 Cable Breaking Strength

The finished cable has a designed minimum breaking strength of 89 kN (20,000 lb).

4.5 Armoring

The armoring operation compressed the core to a 7.87 mm effective final diameter. This was caused by embedment of the armor wires into the polyethylene jacket and volume compression of the core.

4.6 Inner Armor Layer

The first armor layer consisted of 18 GIPS wires helically applied around the core with a 7.64 cm right-hand lay. The armor wires are as indicated in paragraph 2.8 and meet the following requirements:

a.	Diameter	1.47 mm (0.058 in)
b.	Tensile load	>18,000 kg/cm^2 (257 kpsi)
c.	Breaking strength	>3.02 kN (697 lb)

4.7 Outer Armor Layer

The last armor layer consisted of 36 GIPS wires helically applied around the core with a 10.24 cm left-hand lay. The armor wires were as indicated in paragraph 2.6 and met the following requirements:

a.	Diameter	0.94 mm (0.037 in)
b.	Tensile load	>18,000 kg/cm^2 (257 kpsi)
c.	Breaking strength	>1.23 kN (276 lb)

4.8 Void-Filling Compound

The void-filling compound was used and applied as described in paragraph 2.2.

4.9 Lay Length of Cable Core

Six insulated conductors and six fibers were helically cabled around the center member with a 7.64 cm right-hand lay.

4.10 Insulated Copper Conductor

The insulated copper conductors meet the following specifications:

a.	Wire size, AWG	#20
b.	Wire diameter (seven strands)	0.96 mm
c.	Insulation	Polypropylene
d.	Insulation wall thickness	0.38 mm

e. Final diameter 1.73 mm

f. Resistance, dc (maximum) 0.035 ohms/m

Direct current resistance, hi pot, and insulation resistance test data is shown in Table 4.0-3.

4.11 Optical Fibers

Six optical fibers, each 0.5 mm in diameter, were provided in the interstices of the cable core. Each optical fiber was used as a separate channel with at least a 100 MHz bandwidth. The fibers met the requirements of paragraph 2.1.1 except that the attenuation specification was taken as a goal after armoring. Table 4.0-1 presents the data taken on the optical fibers before and after the cable was armored.

4.12 Core Cable Designs

Evaluation of two core cable design configurations was performed at NRL in December 1980. The two cable design configurations were fabricated without any manufacturing difficulty. One design has a Kevlar®/epoxy matrix central strength member and the other design has an additional copper conductor in the center.

Three short length samples of each design were submitted to NRL for examination. The cables were subjected to flex-testing for evaluation of design ruggedness. The copper wires were connected

in series for resistance monitoring, and the optical fibers were examined for continuity during the test program.

The result was the selection of the core cable design with the additional copper conductor in the center. The design with the S-glass Kevlar®/epoxy strength member was rejected because of flex-test failures.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Data shown in the testing results in paragraph 4.0 and particularly the optical data shown in Table 4.0-1 indicate that all the optical fibers have met or exceeded design goals in all respects. All of the optical fibers show excellent properties with small increases after cabling and armoring.

These results indicate that the objective of achieving a successful optimized design for the (AN/BSQ5) bias buoy armored tow cable has been achieved.

Subsequent NRL follow-on testing of this cable should show the suitability of the cable design for an operational system.